U.S. DEPARTMENT OF
ENERGY
Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Connected Lighting Systems Research


Pacific Northwest National Laboratory
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PNNL-SA-142480

Project Summary

Timeline

Start date: 10/1/2018 New/Continuing Project
Planned end date: 9/30/2021

Key Milestones (FY 2019)

1. CLS Interoperability report; 3/31/2019
2. CLS Energy report; 6/30/2019

Expected Deliverables (FY 2019)

- 8+ studies/white papers; 1 new test method
- 4+ conference presentations; standards & early adopter support

Budget

Total Project $ to Date:

- DOE: $2400k
- Cost Share: $0

Total Project $:

- DOE: $5600k
- Cost Share: $0

Key Partners

Early adopters	Chicago, OHSU, Sinclair Holdings, Georgia Power, National Grid
Technology developers	Cisco, Cree, Digital Lumens, Enlighted, GE, Hubbell, Itron, Leviton, Philips
Industry consortia	NEMA/ANSI, UL, DLC OCF, Bluetooth SIG, IIC

Project Goals and Outcomes

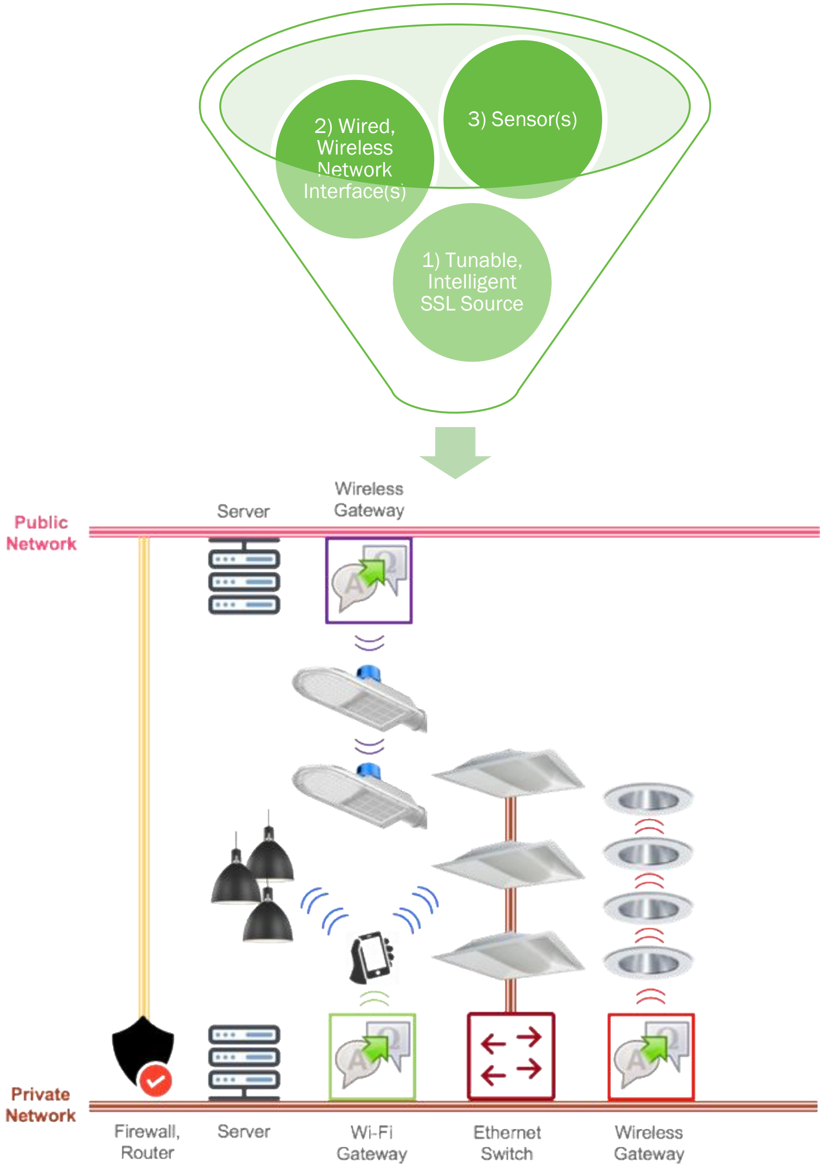
This project aims to maximize the energy savings potential of connected lighting systems (CLS) by answering critical questions about their performance, including whether they will consume more or less energy than traditional lighting systems; how lighting energy consumption can be predicted and verified for deployed CLS, and how CLS can improve the energy performance of other building systems. The project incorporates collaboration with industry stakeholders in all focus areas, and targets early adopter success and the development of performance guidance, specifications, and standards as key outcomes.

Challenge

CLS have the potential to deliver improved lighting performance (energy, lighting quality, occupant satisfaction), improved performance of other building systems (e.g., HVAC energy, security), as well as other valuable data-enabled services. However, at this early stage in their development, they suffer from two key challenges:

*1) Their improved lighting performance does not deliver suitable financial payback based solely on potential energy savings ($**3**/30/300) and is unlikely to do so even if/when first cost comes down. Further, energy performance can be even more difficult to accurately estimate than for conventional lighting control technologies/approaches.*

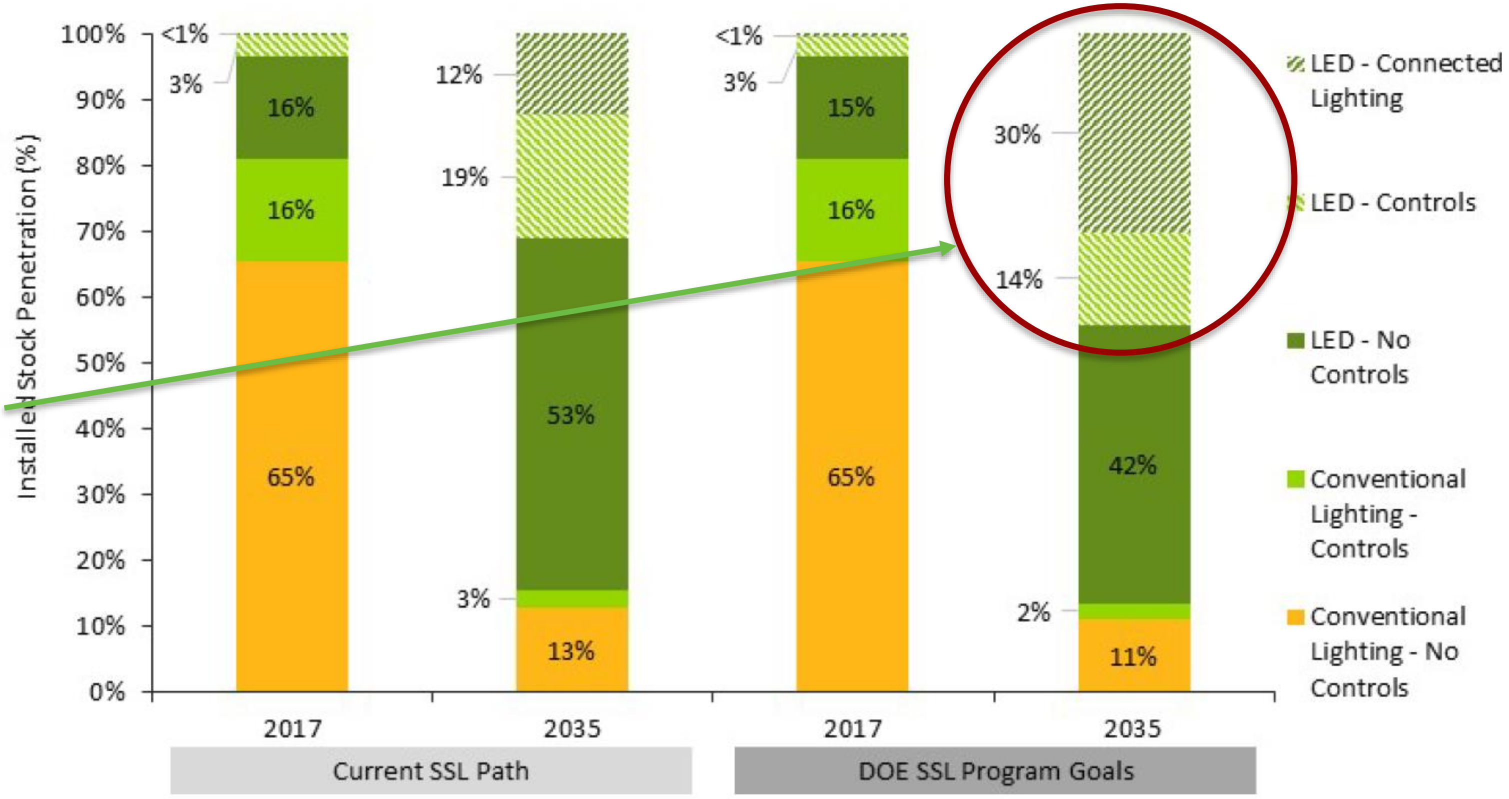
*2) While the value of other services derived from new features that they provide is potentially significant ($3/**30**/**300**), they are unproven, can be difficult to realize and quantify, and introduce new risks (i.e., cybersecurity, compatibility) to lighting systems.*



Goal – Energy Impacts

Under SSL Program Goals scenario, projected annual energy savings attributable to lighting controls in 2030 increases by 48%, from 741 tBtu in the Current SSL Path scenario to 1100 tBtu. Savings increase to 1350 tBtu by 2035 with the installation mix shown below.

CLS data-driven energy management and advanced features are key to reaching these adoption goals



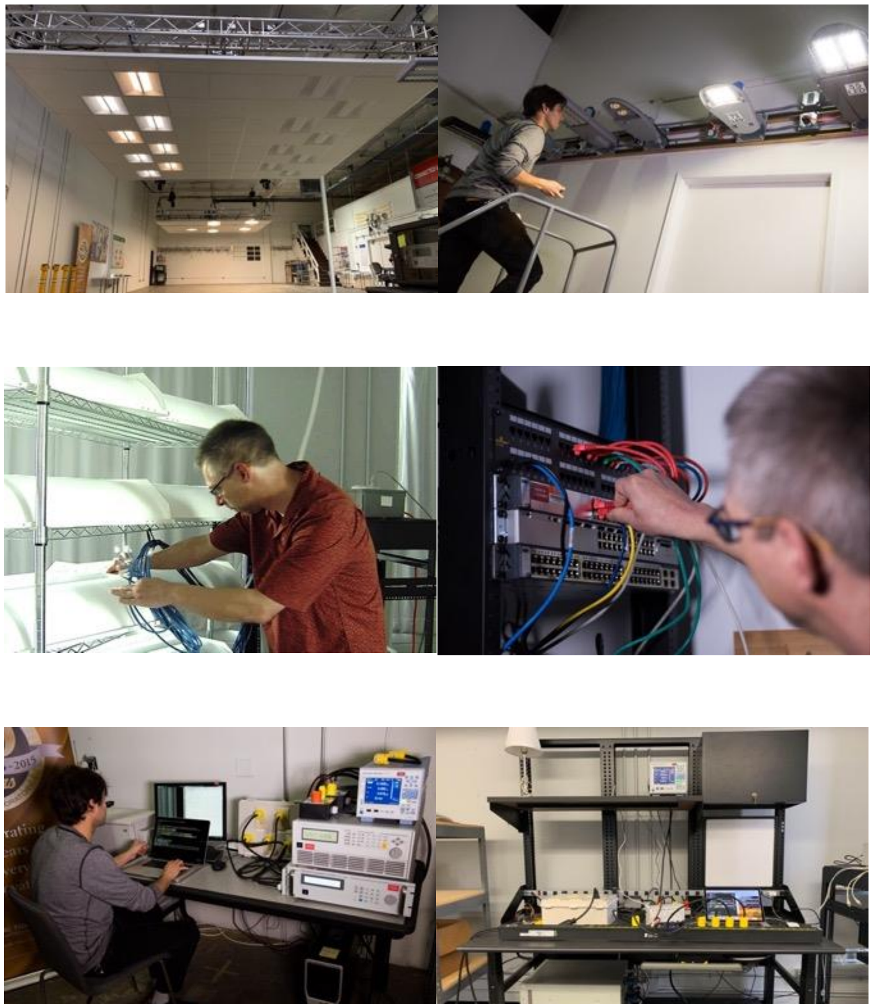
*Energy Savings Forecast of SSL in General Illumination Applications. DOE. 2018. ***Preliminary.***

Approach – Focus Areas

This project aims to reduce the key uncertainties around the energy performance of CLS, and work with early adopters to qualify and quantify the performance and value of other services that have the potential to drive significant market adoption.

Approach – Laboratory & Virtual Test Beds

Connected Lighting Test Bed



Early Adopter Deployments

Approach – Research Topics and Scope

Established in collaboration with early adopters

Identify Opportunity

Nurture Common Interests

Mutually Beneficial

Stakeholder Engagement

Technology developers: Lighting, Building, IT, IoT

Early adopters: Building owner/operators, System Integrators, Certification Bodies

Industry consortia: Standards Development Orgs (SDOs), Specification developers

C12, C136, C137

Stakeholder Engagement

Energy Reporting Accuracy

- Test method development, Experimental scope
- Evaluation, Characterization
- Voluntary standards development and industry adoption

nationalgrid, Georgia Power, TESCO The Eastern Specialty Company, ANSI, NEMA C12, C136, C137

System-Level Energy Performance

- Test method development, Experimental scope
- Evaluation, Characterization
- Performance guidance and specs, Early adopter success

obvius, dmp., The Construction Specifications Institute

Interoperability & System Integration

- Test method development, Experimental scope
- Evaluation, Characterization
- Performance guidance and specs, Early adopter success

OPENAPI INITIATIVE, dmp., OPEN CONNECTIVITY FOUNDATION, Bluetooth, The Construction Specifications Institute

Stakeholder Engagement

Key New Features

- Test method development, Experimental scope
- Evaluation, Characterization
- Performance guidance and specs, Early adopter success

City of Chicago · Georgia Power · Oregon Health & Science University (OHSU) · Sinclair

Cybersecurity Vulnerability

- Test method development, Experimental Scope
- Evaluation, Characterization
- Voluntary standards development and industry adoption

MITRE · Underwriters Laboratories · industrial internet CONSORTIUM · Underwriters Laboratories

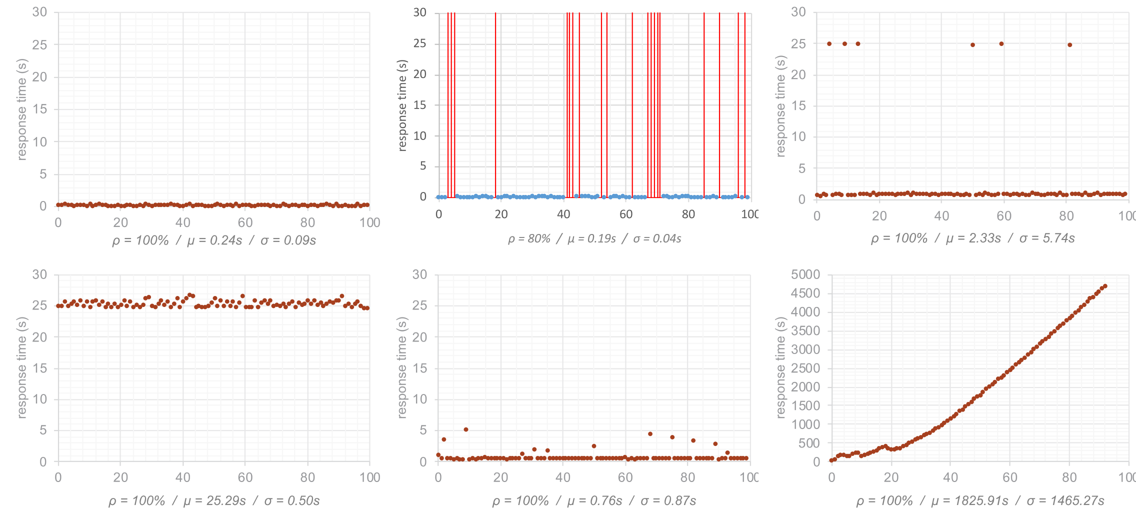
Electrical Immunity

- System integration, Experimental scope
- Evaluation, Characterization
- Performance guidance and specs, Early adopter success

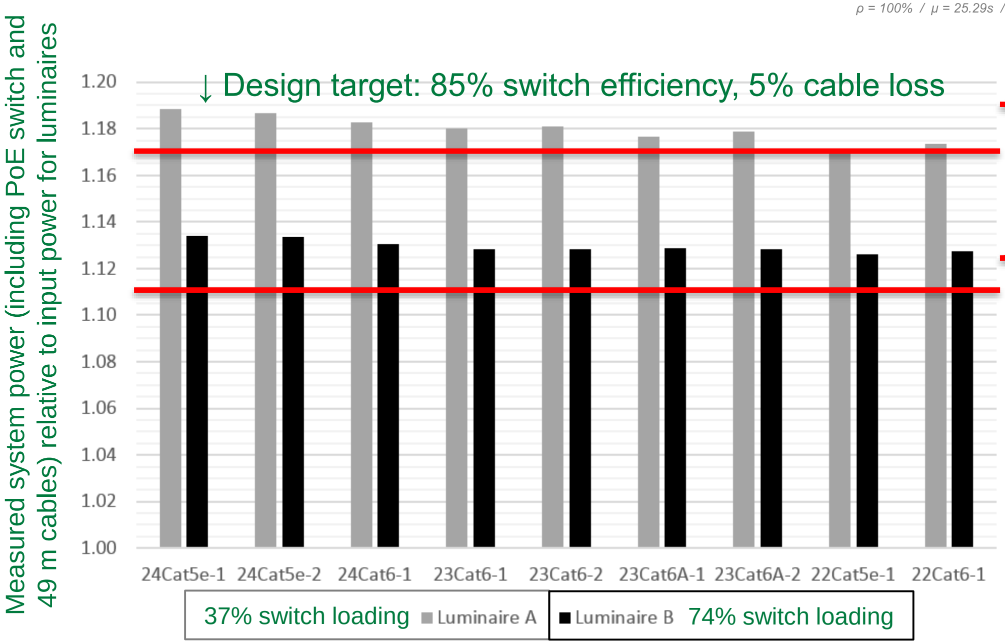
City of Chicago · dmp.

Impact – Technology Development

Response time of six CLS, measured and plotted sequentially 100x



Research characterizes the <u>range of performance</u>, and, if/as applicable, supports and facilitates the development of <u>performance guidance, specifications, and standards.</u>



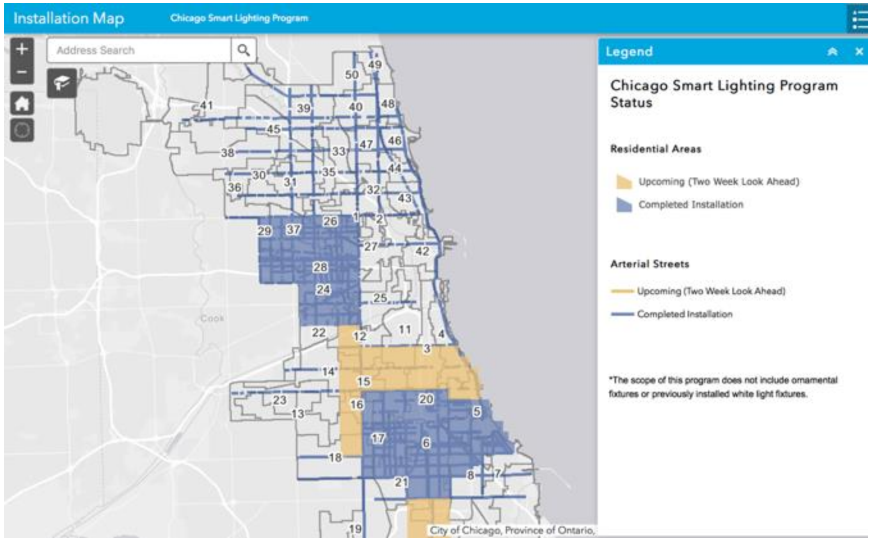
5% range of performance

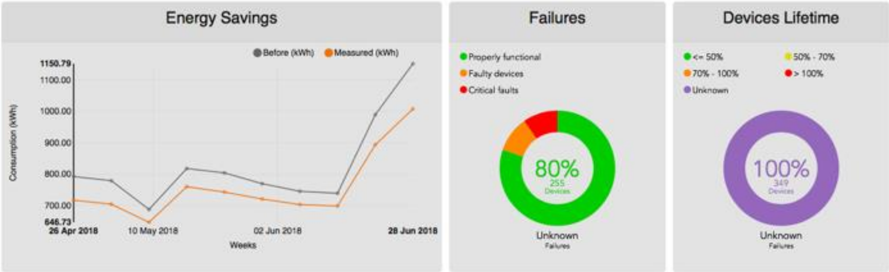
← Design target:
90% switch efficiency,
5% cable loss

- ↑ *2/6 CLS deliver consistent performance, over 25s range*
- ↑ *3/6 CLS do not deliver consistent performance*
- ↑ *1/6 CLS had API immaturity bug*

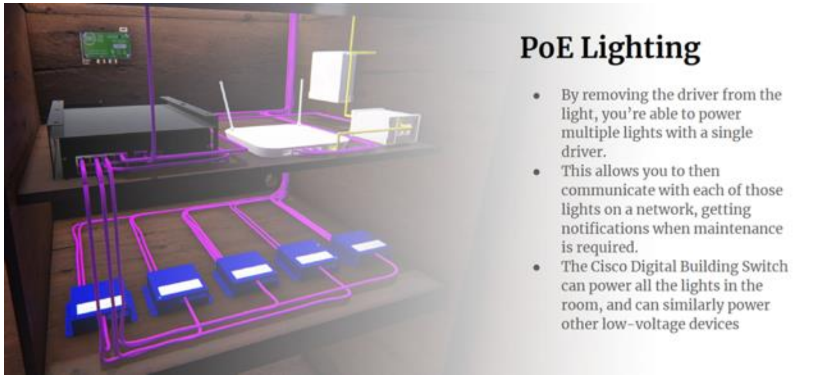
Impact – Early Adopter Success

Chicago is deploying the largest municipal outdoor CLS in the U.S. with 90/270k luminaires retrofitted as of Feb 2019. PNNL assisted the City during their RFI, RFP process with technology characterization and specification-drafting guidance. Chicago has provided PNNL with reported energy data from the deployed CLS, and is developing an ongoing data access MOU.



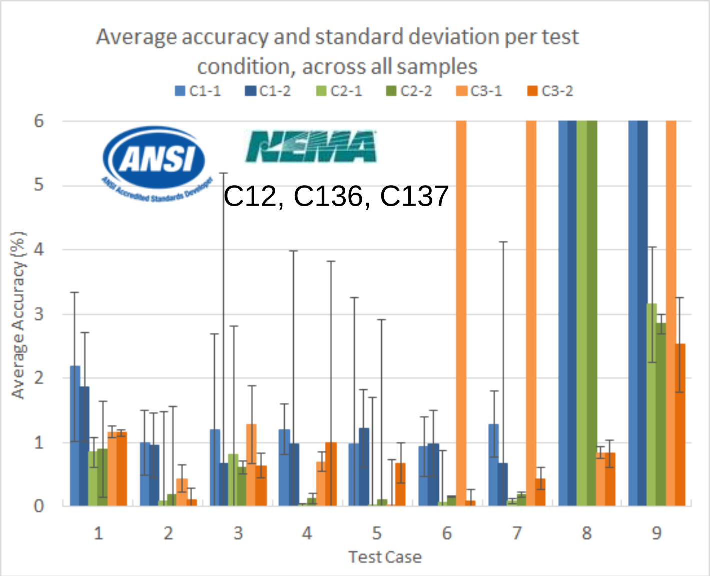


Sinclair Holdings is integrating PoE lighting with many other PoE end-use devices, novel high-power delivery technology, and a lithium-ion energy storage system in projects that promise to significantly decrease both CapEx and OpEx costs. PNNL is working with Sinclair Holdings and Cisco to log the energy data reported by all PoE devices, analyze them in concert with available real-time occupancy data, and explore approaches and techniques for implementing data-driven energy performance management.



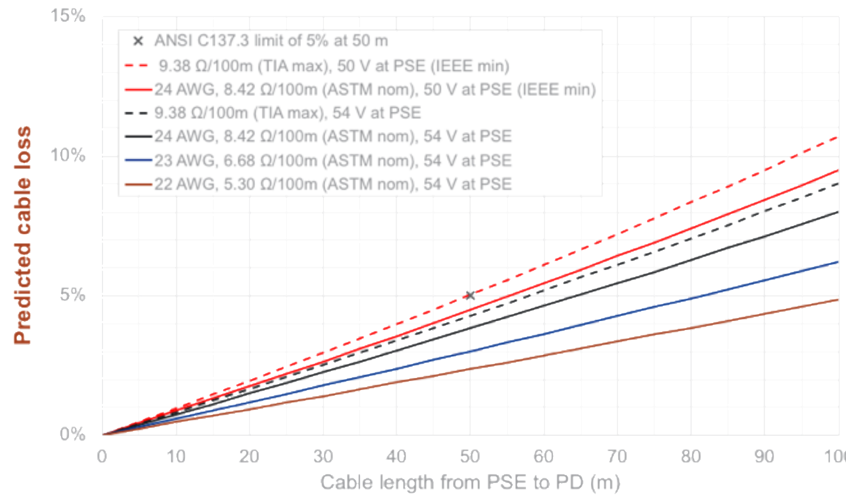
Impact – Industry Consensus

→ Research contributes to the DEVELOPMENT of industry standard <u>energy reporting accuracy</u> test methods, pass/fail criteria, and performance requirements.



↓Research accelerates the ADOPTION of industry standards, recommended practices, and performance requirements via the development of model language that can be used to specify <u>interoperability and system integration</u>.

↓ Research contributes to the VALIDATION of industry standard <u>energy performance</u> recommended practices and performance requirements.



C137

	Task	Item	Task Name
Security	1	SEC 1	Adding System to the Active Network
	2	SEC 2	Virtual Server Software Installation
	3	SEC 3	Active Directory Integration
	4	SEC 4	Access Control Integration and Configuration
	5	SEC 5	Video Surveillance Integration and Configuration
	6	SEC 6	Implement Alarm / Alert Email Notification
	7	SEC 7	Integrate Security Data Exchange with Central Database
	8	SEC 8	Utilize Security Credential for Point of Sale (POS) Purchase

1) Energy Reporting Accuracy

Goals

- Characterize energy reporting accuracy of commercially available CLS, including the impact of both device-level data generation and system-level data collection approaches and technologies
- Characterize the impact of varying statistical representations of energy reporting accuracy over multiple reports and devices, and develop methods for addressing missed data collections
- Support and facilitate the development of standard test methods for characterizing energy reporting accuracy
- Support and facilitate the development of standard energy reporting performance classes that are appropriate for one or more applications (e.g., outdoor lighting energy billing)

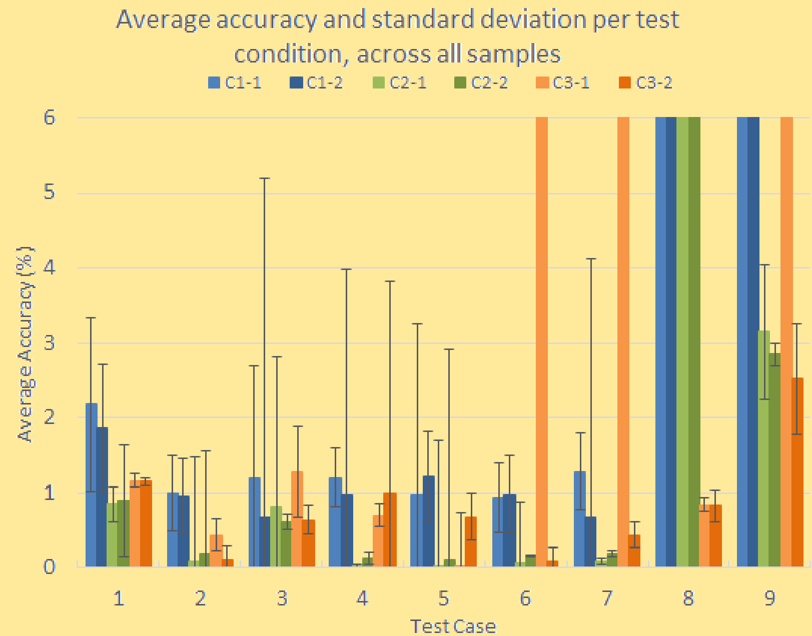
Future Work

- Outdoor CLS circuits
  As reported by sets of streetlight networked lighting controllers
- Connected outlets, part 2
  Additional PDU make/models, more outlets per PDU, multiple measurements per outlet, more statistical analysis
- Streetlight controllers nationalgrid Georgia Power
  Multiple CLS make models, multiple input and load conditions, comparing results across multiple laboratories
- Standards Support ANSI NEMA C12, C136, C137

Progress

Connected Outlets – In Publication Queue

- 2 residential make/models, 3 commercial make/models
- 9 test conditions, varying AC input voltage, AC input voltage frequency, load current, load power factor



- *Wide range of performance variation across different test cases.*
- *Performance for some make/models compromised by limited energy resolution or reporting anomalies from a single sample*

2) System-Level Energy Performance

Goals

- Characterize system-level energy performance of commercially available CLS, including the impact of a) varying system architectures (e.g., direct vs. indirect PoE), b) varying core technologies (e.g., PoE cable type), c) varying application and physical installation characteristics, d) varying network architectures (e.g., star vs. mesh) and e) varying network data levels (e.g., from different sensor types)
- Support and facilitate the development of performance guidance, specifications, and (if/as applicable) standards
- Support and facilitate the development of data-driven energy management strategies

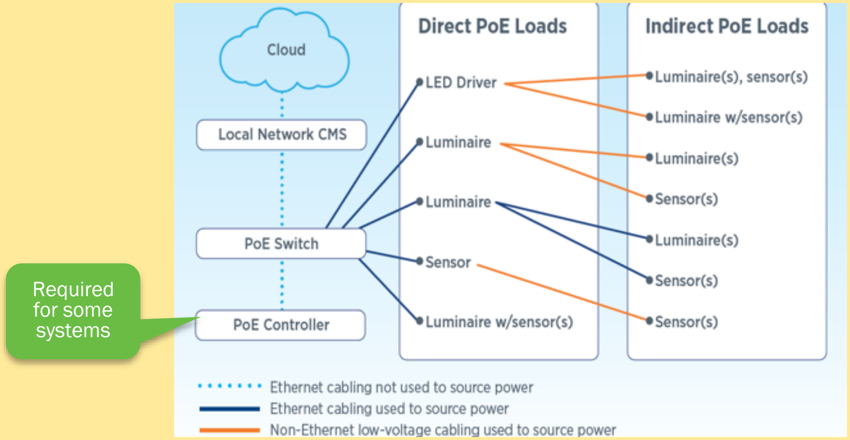
Future Work

- Outdoor CLS circuit energy
  Streetlights controlled by a) shorting cap, b) photocell, c) networked lighting controller
- PoE data-driven energy management
  PoE lighting, PoE lighting and other load types in real-world office space and hotel
- PoE cable energy, part 3
  Higher (IEEE 802.3bt) power per port/cable
- Wireless systems
- AC vs. PoE cable energy simulator (TBD)

Progress

PoE Systems – In Development

- Multiple CLS w/varying system architecture, PoE switch type (central/distributed), PoE cable type
- Varying operating conditions (light output, data traffic)



- *Currently installing and configuring three PoE CLS for system-level testing*
- *Currently exploring opportunities to acquire 1-2 additional PoE CLS, and 1-3 additional PoE switches*

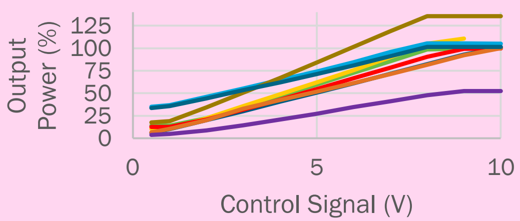
3) Interoperability & System Integration

Goals

- Characterize APIs of commercially available CLS
- Characterize the ability of CLS to be integrated with other CLS or other systems via API integration platforms to implement high-value uses cases
- Validate interoperability claims made by industry consortia by evaluating whether systems comprised of devices that are certified as meeting industry consortia specifications can implement valuable use cases (as identified by early adopters) that require interoperability.
- Support and facilitate the development of performance guidance and model specifications

Future Work

- 0-10V characterization: *Outdoor CLS*

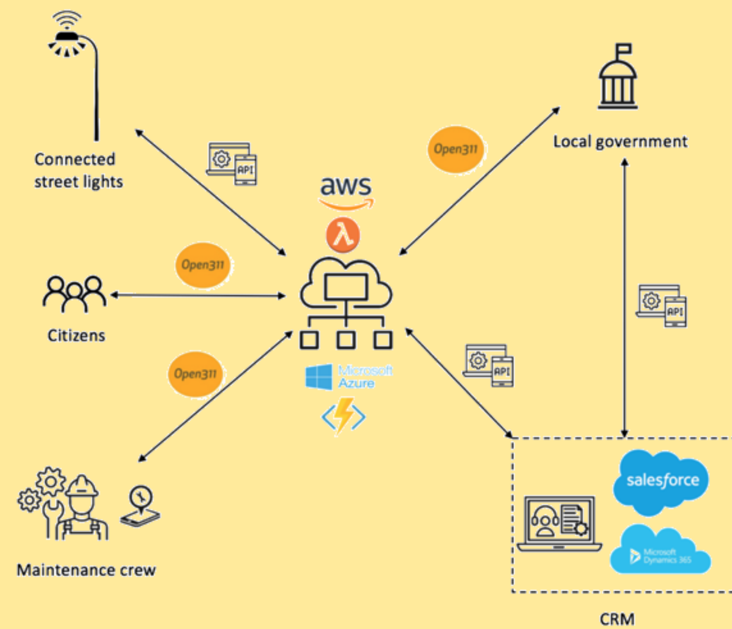


- APIs, part 2: *Additional CLS, new or additional use cases*
- API integration, part 2: *Additional CLS, laboratory characterization*
- Bluetooth Mesh interoperability

Progress

API Integration – In Publication Queue

- 2 CLS, 2 CRMs, 3 API integration platforms



- *CLS1 uses REST interface which supports more data formats, uses less bandwidth, and is easier to develop and test.*
- *CLS2 uses SOAP interface which supports only XML, uses more bandwidth, and is more difficult to develop and test.*
- *Software simulation of 3 system integrations reveals varying levels of maturity and automated functionality among CRMs & API integration platforms.*

4) Key New Features

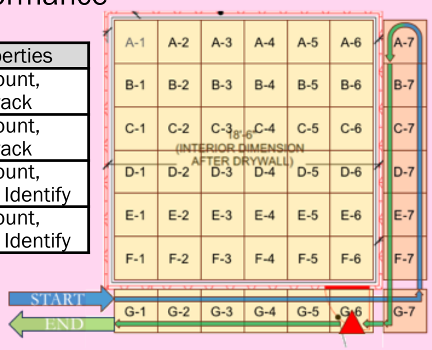
Goals

- Characterize range of performance for key new features that might result in significant improvements in data-driven energy performance, or drive significant adoption of CLS
- Support and facilitate the development of performance guidance and model specifications
- Support early adopters in successful demonstration of value provided by characterized key new features

Future Work

- Indoor occupancy sensor performance

Technology	Availability	Potential properties
PIR	Currently Available	Presence, Count, Location, Track
Digital PIR	Currently Available	Presence, Count, Location, Track
RF Network Diagnostics	Entering Market	Presence, Count, Location, Track, Identify
Video	Entering Market	Presence, Count, Location, Track, Identify



- Outdoor CLS power data retrieval
- Outdoor CLS asset data retrieval
- CLS maintenance
- Indoor space utilization
- Indoor asset tracking

CITY OF CHICAGO INCORPORATED 4th MARCH 1837

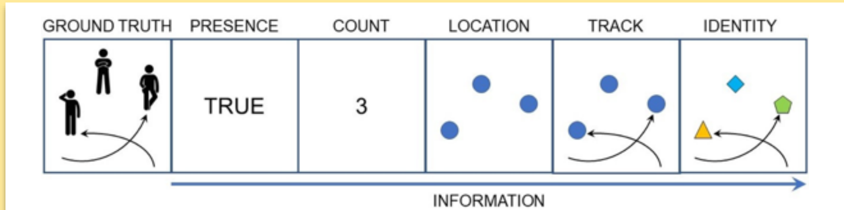
Georgia Power

OREGON HEALTH & SCIENCE UNIVERSITY

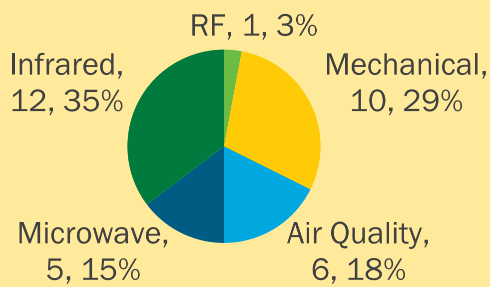
Progress

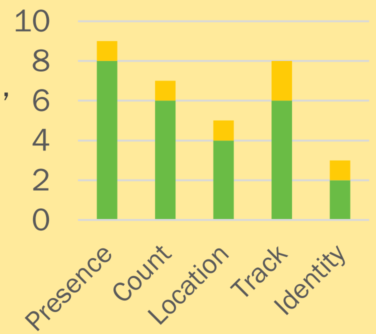
Occupancy sensor performance characterization literature review – In Publication Queue

- *Identified classification approach which defines 3 types of observable properties (spacio-temporal, behavioral, physiological)*
- *Reviewed 30+ studies characterizing sensors using 5 technology types*
- *Categorized studies according to which of the 5 hierarchical spacio-temporal properties were characterized, and whether sensor performance was compromised by presence detection loss*



Spacio-temporal properties





5) Cybersecurity Vulnerability

Goals

- Develop relationships with industry experts who can aid in the development of test methods for known vulnerabilities
- Characterize cybersecurity vulnerabilities of commercially available CLS
- Support the development of performance guidance, specifications, and standards
- Support the characterization and development of IT-OT integration strategies that best support the risk management of cybersecurity vulnerabilities

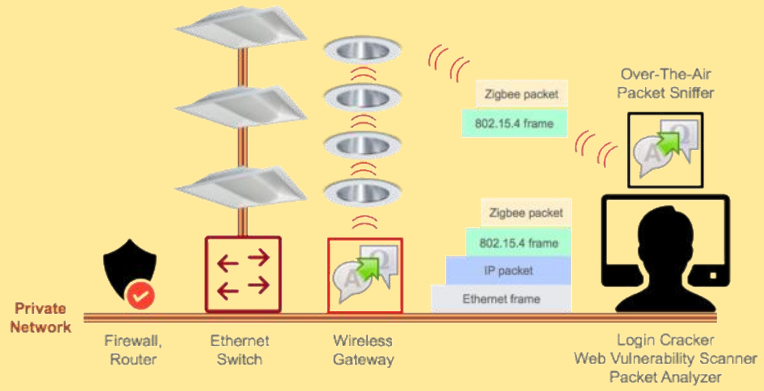
Underwriters Laboratories MITRE industrial internet CONSORTIUM CSI Building Knowledge Improving Project Delivery

Future Work

- Authorization testing
  New tests, Multiple CLS
- Authentication, part 2
  Additional CLS, possibly additional tests

Progress

Authentication vulnerabilities – In Publication Queue



CLS A	CLS B	CLS C	CLS D*
Applicable: 10	Applicable: 11	Applicable: 10	Applicable: 10
>PASS: 3 FAIL: 6	>PASS: 9 FAIL: 2	>PASS: 7 FAIL: 3	>PASS: 7 FAIL: 3
>N/AVAILABLE: 1	>N/AVAILABLE: 0	>N/AVAILABLE: 0	>N/AVAILABLE: 0
30% PASS	82% PASS	70% PASS	70% PASS
Not applicable: 8	Not applicable: 7	Not applicable: 8	Not applicable: 8

*Cloud interface only

- *18 tests defined, 4 CLS, 41/72 applicable*
- *26 pass, 14 fail, 1 Not Available*
- *3 fails, 52% pass range of performance*
- *All CLS pass Test 2: Use of Default Web Credentials and Test 5: Insecure Remember Password Functionality*
- *All CLS fail Test 6: Session Timeout*
- *Test 11, 12, 13 not applicable to any CLS, as none use JSON web token*

6) Electrical Immunity

Goals

- Characterize electrical immunity of commercially available CLS for specific applications and system integrations
- Support the development of performance guidance and model specifications

Future Work

- Correlation of increased infant mortality rates of outdoor CLS with outdoor electrical distribution circuit disturbances
- Indoor CLS integration with battery storage systems
- Indoor CLS integration with battery storage and renewable energy generation systems

Progress

Outdoor CLS immunity to electrical distribution circuit disturbances – In Development

- *Analysis of municipal streetlight electrical distribution circuits where increased infant mortality rates of networked lighting controllers have been observed reveals significant voltage regulation violations, associated current spikes and shifts, and apparent ground faults.*
- *Developing test plan to reproduce observed electrical conditions, and characterize acute effects on outdoor CLS*

Team

Michael Poplawski
EE/SS-Physics/PI
20/9 years

Kelly Gordon
Public Policy/PM
30/19 years

Jason Tuenge
AE/Codes-Standards
19/10 years

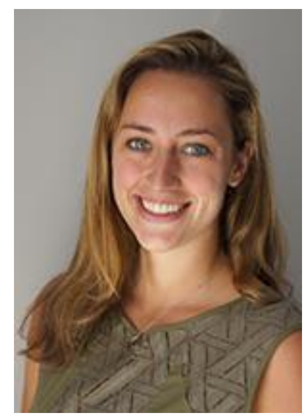
Benjamin Feagin
AE/Control-Sim
8/1 years

Anay Waghale
EE/Power
1/1 years

Alex Vlachokostas
EE-CS/Mod-Sim
4/4 years

Hung Ngo
CS/Apps-Sim
9/9 years

Jaime Kolln
EE/Power, Immunity
1/1 years



Sarah Safranek
AE/Mod-Sim
2/2 years

Thank You

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REFERENCE SLIDES

Project Budget

Project Budget: $1.6M/year for three years (FY 2019 – FY2021)
Variances: No variances; project is on track to planned budget.
Cost to Date: as of March 2019 month end: $694k cumulative cost to date
Additional Funding: None

Budget History					
FY 2018 (past)		FY 2019 (current)		FY 2020 – FY 2021 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
N/A	None	$2400k*	?	$3200k	?

*Note: Includes FY2018 carry-over funds

Project Plan and Schedule

		Task	Description	Due Date
FY19	KM1	3.1	Complete one Interoperability and System Integration study	3/2019
	KM2	1.1	Complete one Energy Reporting Accuracy study ✓Scope	6/2019
	KM3	2.1	Complete one System-Level Energy Performance study ✓Scope	6/2019
	KM4	4.1	Complete one Key New Features study	9/2019
FY20	KM1	1.2	Complete one Energy Reporting Accuracy study ✓Scope	3/2020
	KM2	4.2	Complete one Key New Features study	6/2020
	KM3	5.1	Complete one Cybersecurity Vulnerability study ✓Scope	6/2020
	KM4	6	Complete one Electrical Immunity study	9/2020
FY21	KM1	3.2	Complete one Interoperability and System Integration study	3/2021
	KM2	2.2	Complete one System-Level Energy Performance study	6/2021
	KM3	5.2	Complete one Cybersecurity vulnerability study	6/2021
	KM4	6	Complete one Electrical Immunity study	9/2021
TBD	KMA	3.3	Complete One Interoperability and System Integration study	TBD
TBD	KMB	4.3	Complete on Key New Features study	TBD